A METHOD OF COLLIDING BEAM

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We will make two identical storage rings (or accelerators) stacked together up and down (or side by side) as shown in Fig. 1. There are some number of long straight sections, where the beam is steered up and down vertically (or in and out radially) with the aid of special vertically-bending magnets.

For the colliding beam of the same charge, e.g., p-p, e^--e^-, etc., the magnetic field in two gaps of the ring is in the opposite direction from each other. And the upper and lower beams are circulating in the different direction. There are a pair of vertically bending magnets on both ends of the long straight section as shown in Fig. 2. There the beams are steered up and down into the intermediate plane of the two rings, and they do head-on collision at the central region of the long straight sections.

For the colliding beam of the different charge, e.g., p-p^-, e^--e^+, etc., the magnetic field in two gaps is in the same direction, and two beams are circulating in the different direction from each other. At both ends of the long straight section, there is a pair of vertically beinding magnets, one each beam as shown in Fig. 3. The beams are directed to the center of the long straight section and two beams collide with a small angle. The colliding angle can made smaller by adding another pair of vertically bending magnets next to the already installed pair of magnets.

I. The Case for Particles of the Same Charge

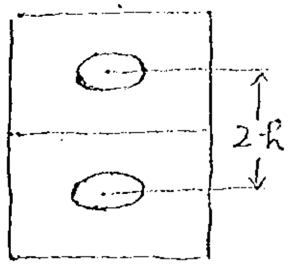

Fig. 1

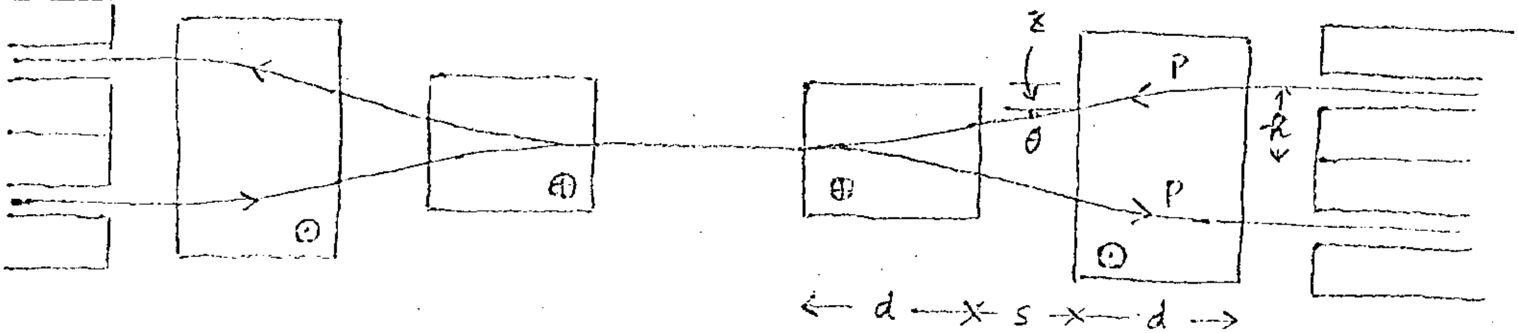

Fig. 2

The distance between the centers of the two vacuum chambers is 2 x h meters. At one end of the straight section there are a pair of bending magnets with their field reversed from each other. As a simple case the magnetic lengths of two bending magnets are taken same d, and the length between two is S. We calculate the total necessary length and minimize it.

The approximate deflection angle θ and deviation Z through a magnet is given by,

$$\theta = \frac{d}{R},$$

$$Z = \frac{d^2}{2R} = 1/2\ \theta d,$$

where R is the radius of the curvature of the beam in the gap of the vertically bending magnet and may be taken same as the radius of the curvature of the main ring. R is given by

$$R = \frac{P}{300B}, \quad R\text{: m, B:weber/m}^2\text{, and P:MeV/c.}$$

Then h is given by

$$h = 2Z + S \cdot \theta = (d + S) \cdot \theta = (d + S) \cdot \frac{d}{R},$$

$$S = \frac{hR}{d} - d.$$

The total length L of this half system is given by

$$L = 2d + S = d + \frac{hR}{d}.$$

To minimize L,

$$\frac{\partial L}{\partial d} = 1 - \frac{hR}{d^2}.$$

From $\frac{\partial L}{\partial d} = 0$,

$$\frac{hR}{d^2} = 1, \quad d = \sqrt{hR}.$$

Then

$$S = \frac{hR}{\sqrt{hR}} - \sqrt{hR} = 0,$$

$$L = 2\sqrt{hR}.$$

Therefore, the length L is minimum when there is no drift space between the two bending magnets. The minimum total length L_o of the straight section for bending is twice the value given above and is given by $4\sqrt{hR}$. R is proportional to the momentum of the beam and the necessary total length is proportional to $\sqrt{p}$. The ratio of this section to the total circumference is decreasing with the increase of the energy, as the distance between the centers of the beams is constant regardless the energy of the beam.

The examples

1) 200-400 BeV Machine

Mean radius = 10^3 m, R = 740 m, 2h = 0.3 m

$$L_o = 4\sqrt{hR} = 4\sqrt{0.15 \times 740} = 42 \text{ m}$$

$$d = \sqrt{hR} = 10.5 \text{ m}$$

We may need some allowance of the order of 10 m ~ 20 m for installing drift space, Q magnets and an experimental area. The long straight section of this length 50~60 m is feasible with the present technology.

2) 10 BeV

Main radius = 100 m, R = 36 m, 2h = 0.3 m

$$L_o = 4\sqrt{hR} = 4\sqrt{0.15 \times 36} = 9.3$$

$$d = \sqrt{hR} = 2.3 \text{ m}$$

We may need some allowance of the order of 5 m. The total length will be about 14 m.

3) 1 BeV

R = 4 m, 2h = 0.3 m

$$L_o = 4\sqrt{hR} = 4\sqrt{0.15 \times 4} = 3.1 \text{ m}$$

$$d = \sqrt{hR} = 0.78 \text{ m}$$

The particle can go in two ways as follows. In the first case the direction of the magnetic field of two rings is made different from each other. The beam in the upper ring stays there and comes down half way the distance between the centers of two vacuum chambers, only in the long straight sections as shown in Fig. 2. The beam in the lower ring comes up in the same straight sections and collides head-on with the upper beam. In this case two beams may be kept apart until they are stacked enough or accelerated. In the second case, the direction of the magnetic field of the main ring is reversed at every long straight sections. Therefore, the beam in the upper ring goes downward at the long straight section and gets into the lower ring. The beam, which was in the lower ring, comes up and collides with the other beam.

If it is necessary we may put quadrupole magnets in the collision area.

II. The Case for Particles of Different Charge

In this case the vertical steering magnets as shown in Fig. 2 are all split into halves, and the direction of the magnetic field is reversed from each other. The magnets near the center of the straight section may be made like a magnetic slit.

The direction of the magnetic field of two rings is made the same. Two beams are circulating in the opposite directions and switch from one ring to the other in the long straight sections. The beams collide each other at the center of the straight section. In this case they do not collide head-on but with a small angle depending on the vertically-bending magnets. The necessary length of the long straight section may be of the order of that for the case of particles of the same charge. The length may be made shorter by eliminating the inner steering magnets as shown in Fig. 3, but the angle of collision becomes bigger.

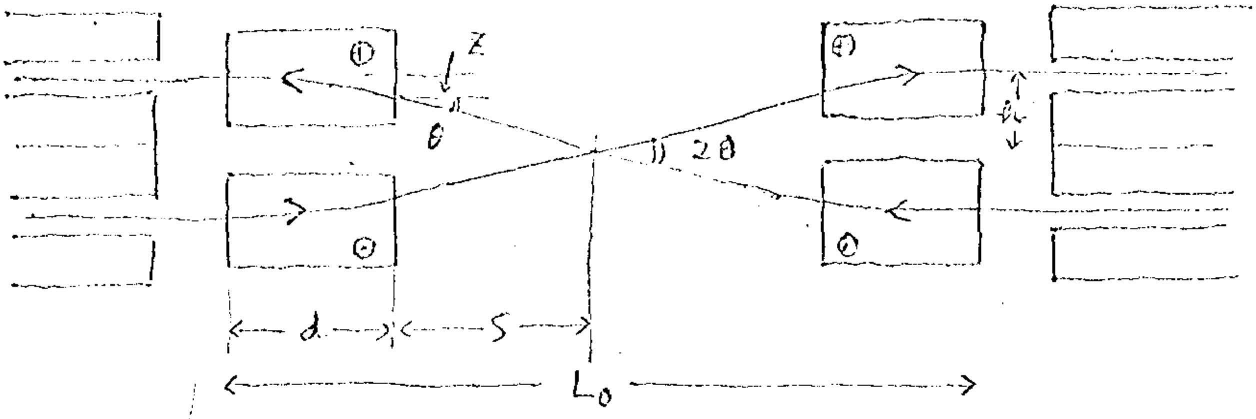

Fig. 3

We calculate the colliding angle 2θ and d for a system with given h and total length L_o.

$$S = \frac{L_o}{2} - d = \frac{L_o}{2} - R\theta,$$

$$h = Z + S\theta = \frac{d^2}{2R} + S\theta = \frac{R}{2}\theta^2 + \frac{L_o}{2}\theta - R\theta^2.$$

Then

$$R\theta^2 - L_o\theta + 2h = 0,$$

$$\theta = \frac{L_o \pm \sqrt{L_o^2 - 8hR}}{2R} = \frac{L_o}{2R}\left(1 \pm \sqrt{1 - \frac{8Rh}{L_o^2}}\right).$$

L is longer than 2Rθ. Therefore, θ and d are given by the following equations.

$$\theta = \frac{L_o}{2R}\left(1 - \sqrt{1 - \frac{8Rh}{L_o^2}}\right),$$

$$d = R\theta,$$

As θ should be real

$$L_o \geq \sqrt{8Rh} = 2\sqrt{2}\sqrt{Rh}.$$

Therefore, the minimum total length L_o in this case is shorter by a factor of $\sqrt{2}$ than that for the case of the same charge. The vertical steering magnets for this case can be two-gap magnets with the same yoke and coils.

When the h and d is given, the values of S and θ are given as follows:

$$\theta = \frac{d}{R},$$

$$S = \frac{R}{d}\left(h - \frac{d^2}{2R} \right).$$

III. Merits of this System

The cost of this type of magnets is cheaper than that of two same magnets, which may be used together as a colliding system. Two magnets can be made in a unit. If we use C-type magnet, the core lamination for two rings can be made in a punch. The cost in its construction, transportation, installation and survey is cheaper and this type may be made quicker. If RF cavities are needed, they may be put in one of the straight sections and can be used for two beams simultaneously.

The tunnel cost can be greatly reduced, because it is almost equivalent to that of only one ring system. Intersecting storage ring needs a much wider tunnel which is costly, and two ring type needs double that for this type.

In the system of the same charged particles the beams can be made to collide head-on for quite a long distance in several long straight sections. The production rate of collision can be made big, which is proportional to the length and to the number of straight sections. This means much more reaction rate can be obtained in this system.

By taking out the vertically bending magnets, the ring can be used as a two-storied accelerator or booster. From this kind of considerations, it may be good if the magnet of the ring is built as a separated function type composed of bending magnets and quadrupole magnets, which makes it possible to be used differently. If we are interested only in the case of beams of the same charge, we can make a magnet with two gaps and with top and bottom yokes in one magnetic circuit.

The type of side-by-side magnet also can be made from one punch of sheet. The distance between the centers of the vacuum chamber is kept constant and the radii of the two rings are different from each other but constant. The beam is steered radially instead of vertically.

If we could use superconducting magnets for the radially and vertically bending magnets, the radius of the ring and the length of the vertically bending magnets can be reduced to a great extent. The quadrupole magnets may be made of regular iron or of superconducting material.